SLEEP STAGES, MEMORY AND LEARNING

Lydia Dotto

Abstract • Résumé

Learning and memory can be impaired by sleep loss during specific vulnerable "windows" for several days after new tasks have been learned. Different types of tasks are differentially vulnerable to the loss of different stages of sleep. Memory required to perform cognitive procedural tasks is affected by the loss of rapid-eye-movement (REM) sleep on the first night after learning occurs and again on the third night after learning. REM-sleep deprivation on the second night after learning does not produce memory deficits. Declarative memory, which is used for the recall of specific facts, is not similarly affected by REM-sleep loss. The learning of procedural motor tasks, including those required in many sports, is impaired by the loss of stage 2 sleep, which occurs primarily in the early hours of the morning. These findings have implications for the academic and athletic performance of students and for anyone whose work involves ongoing learning and demands high standards of performance.

La perte de sommeil au cours de «créneaux» vulnérables précis pendant plusieurs jours après l'apprentissage d'une nouvelle tâche peut nuire à l'acquisition du savoir et à la mémoire. Des types différents de tâches sont vulnérables de façons différentes à la perte de stades différents du sommeil. La perte du sommeil paradoxal la première nuit après l'apprentissage et de nouveau la troisième nuit après l'apprentissage affecte la mémoire nécessaire à l'exécution de tâches procédurales liées à la cognition. La perte du sommeil paradoxal la deuxième nuit après l'apprentissage ne produit pas de déficit de la mémoire. La perte du sommeil paradoxal n'affecte pas non plus la mémoire déclarative, qui sert au rappel de faits précis. La perte du sommeil du stade 2, qui se produit surtout tôt le matin, nuit à l'apprentissage de tâches motrices procédurales, y compris celles qui sont nécessaires dans nombre de sports. Ces constatations ont des répercussions sur le rendement scolaire et athlétique des étudiants et sur quiconque doit, dans son travail, apprendre constamment et fournir un rendement élevé.

Whether you're studying for university exams, memorizing the script of a play, learning to drive a car or training intensively for an athletic competition, your performance can be affected not only by how much sleep you have had, but also by what type of sleep you got and when you got it, according to Dr. Carlyle Smith, professor of psychology at Trent University, Peterborough, Ont.

Smith has spent years studying the effects of sleep and sleep loss on memory and learning, particularly the role of rapid-eye-movement (REM) sleep, the stage during which most dreaming occurs. His research indicates that different kinds of learning tasks are affected by different sleep stages and that learning can be significantly degraded if sleep loss occurs during vulnerable "windows" for several days afterward.

These findings have implications for the academic and athletic performance of students and, indeed, for anyone whose work involves ongoing learning and demands high standards of performance — for example, pilots and physicians. Staying up all night studying for an exam might be the worst thing a student could do, and there are times when an athlete might be better off sleeping in rather than hitting the skating rink or swimming pool at 5 am, Smith suggests.

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DIFFERENT TYPES OF LEARNING TASKS

Smith's research has focused on the effects of sleep loss on two distinct types of memory: declarative and procedural. Declarative memory involves direct recall from previous episodes of learning; it is used for memo-

Lydia Dotto is a freelance science writer living in Peterborough, Ont.

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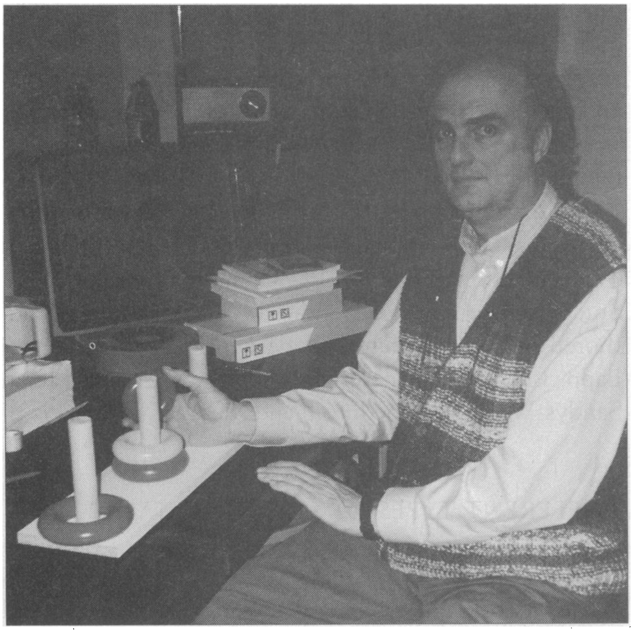
rization and verbatim repetition of specific facts. "Anything where you can repeat back exactly the same material," says Smith. "It's the kind of memory that's quite conscious." Examples include learning the script of a play or remembering dates for a history exam. Declarative tasks used in his experiments include memorization and recall of word lists and pairs of associated words.

Procedural memory is used for behavioural responses that do not involve direct recall from previous episodes of learning. This is the kind of memory we use for tasks that we "know" how to do but for which we do not need — and, indeed, may be unable — to consciously remember the precise details of every step required. "You practise and then you can do them," says Smith. Procedural tasks can be either motor or cognitive. Motor tasks are primarily physical: tying shoelaces, typing, skating or riding a bicycle. Most sports require this kind of memory, and that is why intense, repeated training is necessary for superior performance.

"Did you ever tell somebody how to tie their shoelaces?" asks Smith. "You can't do it. Instead, you say, 'Here, I'll show you.' Or how to skate? Do you give them a printed page and say, 'Here's what you do: you put your skates on, you get on the ice, you place your foot here.' They'll never learn how to skate that way. They have to do it."

Once a procedural motor task is learned it can be repeated, often years later, without conscious memory of the individual elements required to do the task. "Many of the moments that you had learning how to ride a bike are simply not there," said Smith. "You simply know how to do something."



Dr. Carlyle Smith with the Tower of Hanoi: poor performance of this task indicates REM-sleep deprivation.

As for cognitive procedural tasks, some types of word puzzles, as well as certain math and science problems, fall into this category: they have to be done to be mastered. "When you learn physics or math there are all these formulas. You can give somebody [a formula] and they can memorize it — that's declarative memory — but they have no idea what they're talking about. The understanding of what [it] means seems to be more cognitive procedural: you have to solve the problems and each problem has to be practised on its own. Eventually you do learn the principle but you have to actually work through these tough examples."

One cognitive procedural task Smith uses in his experiments is a puzzle called the "Tower of Hanoi," which involves manipulating rings of different sizes and colours on a wooden pegboard. The object is to move all the rings from one end of the board to the other in as few steps as possible without placing a larger ring on top of a smaller one. Subjects learn how to do it by trial and error.

Some complex tasks involve several different types of memory. Driving a car, for example, requires both motor and cognitive memory, and "probably declarative too," Smith said. "It's a mixed task. I don't think there is a 'pure' task." However, for many tasks, one type of memory may dominate the learning process — and this is what makes them differentially vulnerable to the loss of different stages of sleep.

Different tasks affected by different stages of sleep

In a normal 7- to 8-hour sleep period, there are five sleep cycles of roughly 90 minutes' duration, each of which contains different sleep stages: stage 2, a comparatively light sleep; stage 3/4, also known as slow-wave sleep or deep sleep, the "dead-to-the-world" kind of sleep believed to be most important for physical and psychological restoration; and REM sleep, during which the sleeper is very near consciousness and likely to be dreaming. Deep sleep is concentrated in the first two cycles, while the lighter stages, stage 2 and REM, dominate the later cycles. During each cycle, the sleeper goes through stage 2 on the way "down" to slow-wave sleep and then again on the way "up" to REM sleep.

Numerous studies have revealed a relation between memory and REM sleep.[1–6] In humans, increases in REM density (the number of rapid eye movements per minute of REM sleep) can be observed on the first night after complex information is learned — but, interestingly, not on the second night — and then again for several nights afterward. Interrupting REM sleep during specific vulnerable "windows" in this period of increased REM activity can cause substantial deficits in the ability to recall the learned tasks. However, REM sleep can be interrupted at times other than during the vulnerable windows without memory impairment.

"Night two doesn't matter as long as you don't learn anything new [that day]," says Smith. "If you learn Monday and you take Tuesday off, you can stay up that night." However, sleep deprivation on the third night after learning causes memory deficits.

Smith has conducted numerous experiments with student volunteers to demonstrate these effects of sleep deprivation, especially REM-sleep deprivation, on memory. In one study, subjects were tested using both verbal and nonverbal declarative tasks (e.g., word lists and paired associates) and verbal and nonverbal procedural tasks (e.g,. the Tower of Hanoi).[7] Five groups were tested. Two control groups had normal sleep after learning the tasks, one group at home and the other in the sleep lab. A third group was kept awake all night. The fourth group was selectively deprived of REM sleep during the last two sleep cycles of the night, when most REM sleep occurs. Finally, a fifth group was awakened the same number of times as the group deprived of REM sleep, but during non-REM sleep stages.

When tested a week later on the Tower of Hanoi (a cognitive procedural task) the two control groups improved their baseline performance, as did the group awakened during non-REM sleep. Those who had had total sleep deprivation and the group deprived of REM sleep did considerably worse; in fact, the latter group fell below baseline levels.

Declarative tasks, on the other hand, seem to be immune to sleep deprivation, says Smith. None of the five groups in the experiment showed impairment when tested on declarative tasks a week later. "We've given them word lists and paired associates but they're not affected. You can keep people up all night and they still do fine."

These and other experiments Smith has conducted indicate that the performance of cognitive procedural tasks by subjects deprived of REM sleep shows a deficit of roughly 20% to 30% compared with that of rested subjects and with their own baseline performance.[7-9]

Smith is currently investigating whether alcohol consumption can produce similar memory and learning deficits as a consequence of its well-known disruptive effect on REM sleep. So far he has found that if subjects drink alcohol on the night after a new task is learned and on the third night afterward they perform poorly when retested a week later. These results are similar to those obtained by waking subjects during REM sleep in the first- and third-night windows when memory is vulnerable to REM-sleep loss.[10] Students who drink on Thursdays, Fridays and Saturdays — a typical pattern among university students, Smith says — take a hit on material they learned not only on each of the three days they drank, but also on the two days preceding each of those days (i.e., Tuesday, Wednesday and Thursday). The implication is that weekend alcohol consumption could impair learning that occurred during most of the week.

Memory and learning deficits also occur when the normal sleep period is delayed for a few hours, according to Smith's research. "We found the same thing if we asked people to stay up for 4 hours and then go home to bed." These subjects were not sleep deprived: they reported sleeping in as long as they wanted to the next morning. They had simply shifted their normal sleep schedule, yet this affected their ability to recall complex information. "You have to get [REM sleep] when your body expects you to get it," suggests Smith.

To retain complex information, getting all of your normal REM sleep at the time your body is conditioned to have it provides the best results.

This means that staying up late to cram for an exam — unless it mainly involves straightforward memorization — is probably a bad idea. To retain complex information, getting all of your normal REM sleep at the time your body is conditioned to have it provides the best results.

Smith also suggests that students who have a relatively stable sleep routine most weekday nights but stay up late on weekends should concentrate procedural learning near the beginning of the week and leave declarative learning until near the end of the week, since the declarative learning will not be affected by weekend sleep loss as much as procedural learning would be. "If you could learn most of the tough procedural material Monday and Tuesday, by Friday you wouldn't have to worry about it." Some of Smith's students actually figured out when they could stay up late and when they could not. "One girl was really successful. As soon as she heard about this, that's what she did. She organized her life around that and she's doing really well."

Smith says that these findings also have implications for shift workers, especially those whose jobs require them to process complex information. "Nurses, doctors, airline pilots, cops — all these people who you hope really know what they're doing," he said. "Those are the people I would say are at risk. Their hours are always switching."

Motor tasks affected by a different type of sleep

In another study Smith had subjects learn a fine-motor task called the "pursuit rotor," which required them to follow a dot around a screen using their nonpreferred hand.[11] He found that total sleep deprivation on the first night after learning the task impaired performance when the subjects were retested a week later, but that total sleep deprivation on the second night did not impair performance.

In a subsequent, more detailed, experiment[12] Smith tested five groups: a normally rested control group; a group totally deprived of sleep; a group whose REM sleep was interrupted at the onset of every REM period during the night; a group that was awakened during non-REM periods the same number of times as the third group was awakened; and a group that received 4 hours of normal sleep and then was kept awake for the last half of the night, when most stage 2 and REM sleep is normally obtained.

The results were surprising. The group deprived of REM sleep did not, as Smith and his collaborators had hypothesized, exhibit significant memory deficits when retested on the procedural motor task a week later; in fact, they did nearly as well as the control group. Instead, the group that had total sleep deprivation and the group deprived of sleep in the last half of the night had the worst memory deficits. "Since the most prevalent types of sleep in the last half of the night are stage 2 and REM sleep, and since REM deprivation did not impair memory for the task, these results suggest that stage 2 sleep . . . rather than REM sleep was the important factor in the memory of the pursuit rotor task," Smith observed in his paper.[12]

The group that was awakened during non-REM sleep showed a slight impairment that, although not statistically significant, suggested that continuous stage 2 sleep is preferable to interrupted sleep in the learning of procedural motor tasks.

"The amazing thing about motor memory is that when you come back the next day, you are 20% to 25% better, presuming you've had a normal night's sleep," says Smith. "However, if you don't get your stage 2 the night after you've been doing this task, or if you get stage 2 that's interrupted a lot, you don't improve; you start where you started last time. It's not just the amount of stage 2, but the amount of uninterrupted stage 2." The discovery that stage 2 sleep is important for learning motor tasks came as quite a surprise, he adds. "No one's found a use for it; some consider it to be filler sleep, junk sleep. There's a lot of talk that it's just there to keep the night together."

One implication of these findings for athletes, says Smith, is that they shouldn't be getting up at the crack of dawn after learning new moves. Instead, they should have "a nice long sleep in the morning — that's when stage 2 occurs. If a figure skater is interested in getting down triple whatevers, he shouldn't be getting up at 4 in the morning. The people who are most at risk here are the ones who are training day after day after day and at the same time are going to school and doing a lot of other things. Morning after morning they're getting up earlier than they should; they're sleep-depriving themselves, but worse, they're cutting off the stage 2 they need. Imagine how hard they're going to have to work compared to someone who gets to sleep in till 10 every morning. All that extra stage 2, and they can go out and do a triple salchow or whatever. This magic increase is wonderful, so why would you want to be out sweating and puffing on the ice when you can just lie there in bed?"

No doubt it would be a tough sell persuading athletes — or, more important, their coaches — to adopt this unconventional "lying-abed" approach to training for the Olympics. Still, giving more attention to the impact of stage 2 sleep loss on athletic performance could potentially pay off on the podium.

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